W.E.S.C.

COSTING ANNEXE TO

CONSULTANTS PRELIMINARY REPORT

1977

WAVE ENERGY STEERING COMMITTEE

UNITED KINGDOM WAVE ENERGY PROGRAMME

COSTING ANNEXE TO CONSULTANTS PRELIMINARY REPORT

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COST ANALYSIS OF WAVE POWER DEVICES

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COST ANALYSIS OF WAVE POWER DEVICES

SUMMARY

1. GENERAL REMARKS

The procedure for costing the Reference Designs of the Wave Power Devices is described in Chapter 3 of the Consultant's Preliminary Report. The detailed breakdown of the prices determined for each Device, together with tabulated comparisons of the data received from contractors, is given as an Appendix to this Cost Annexe.

The following tabulated summaries cover the overall capital cost of the construction of a 200 MW installed capacity power station for each Device. They should not be taken outside the context of the Consultants Preliminary Report, in which the reservations to be placed both on the preliminary Reference Designs and on the preliminary costing exercise are clearly stated.

During this study, time did not permit the exploration of the many avenues which are available for potential cost reduction both by redesign and the study of alternative construction procedures. In particular there has been no opportunity for discussion of the costing exercise with the Device Teams.

However, a study of the cost breakdowns indicates areas in each Device where cost savings should be achieved by appropriate design changes or more detailed analysis.

2. TABULATED SUMMARIES

Summary Tables 1 and 2 show the breakdown into seven broad cost areas of the basic capital cost for a 200 MW output power station for each Device. Table 1 gives the estimated cost of each category for each Device, whilst Table 2 indicates these costs expressed as a percentage of the total cost for each Device.

3. CONCLUSIONS DRAWN FROM COST ANALYSIS

3.1 Examination of Table 2 gives an indication of where the major cost areas for each Device lie and where design effort might be concentrated to greatest effect to achieve substantial cost reduction. Within the broad categories chosen for the Summary Tables there are certain cost items for each device which contribute a major portion to the total cost of each category and which particularly warrant a more detailed study. The following comments draw attention to these cost-sensitive areas for the Devices.

3.1.1 Sea Energy Associates

(i) Construction of the Concrete Spine and Beak Units (51% of the Total Cost)

In assessing the cost of construction, time did not permit a detailed study to be made of various possible methods of construction and in particular no help was sought from a Contractor to determine a reasonable programme. The derived cost was based on a 12 month programme for the casting and assembly of

7 beak and spine units and since the overall cost of the concrete construction is sensitive to the time element (to say ± 15%), this aspect should be discussed and reviewed with contractors in order to obtain a better evaluation.

(ii) Beak/Spine Roller System and Seals (19 % of the Total Cost)

Further development work should reduce the high cost of these two items.

(iii) Mechanical Components to Power Take-off (9% of Total Cost)

By far the biggest contributor to this item is the rack and roller path for the pinion drive. Advice was sought from a leading manufacturer in order to assess the possible thickness of material for this component as well as the likely order of cost. However, no design studies were undertaken and it is reasonable to assume that a detailed investigation could result in a reduction in the weight and hence the cost of the rack. For a really useful cost reduction an entirely new method of making the rack must be sought.

(iv) General Remarks

It is significant that the S.E.A. proposed system, if it can be made to work, would eliminate much of the cost in (ii) and (iii) although the cost of the alternative system cannot as yet be estimated. Certainly the present costing confirms the S.E.A. anxiety to avoid the cost of a rack power offtake.

3.1.2 Wavepower Ltd.

(i) Concrete Rafts (38% of the Total Cost)

Since the one contractor who priced this item also submitted the highest price for the H.R.S. and NEL Devices, it was considered reasonable to assess an average price for the rafts of Wavepower Ltd. in the manner described in the Appendix. It is felt that a more detailed design study and an evaluation of possible construction methods may result in substantial savings in this major item.

(ii) Mechanical Components to Power Take-off (12% of Total Cost)

Like the Salter Duck the cost of the rack for the pinion drive together with the cost of the steel guide track for the pinion carriage is the major cost component of the power take off. Further work on the design of these two items could result in substantial savings.

(iii) Anchors and Moorings (14.5% of Total Cost)

The necessity to keep the barges at a safe distance from each other to avoid collision under storm conditions, together with the need to resist considerable wave loadings, has resulted in a very expensive anchor and mooring system for this Device. The whole problem of anchors and moorings is one which must be given considerable attention for each floating device, but particularly so for this Device where the possible cost is disproportionally high.

3.1.3 N.E.L. Device

(i) Concrete and steel structure (74% of the Total Cost)

It is evident from the tabulated Summary of the total cost of the Devices that the high cost of the NEL structure (as interpreted by the Consultants in the Reference Design) must be considerably reduced in order that the scheme may be considered viable. Although the Reference Design employs a certain quantity of fabricated steel sections in order to reduce the overall weight of the structure, it can be seen that this material carries a high cost penalty in addition to its disadvantages from a maintenance aspect.

The option of siting the Device on the sea bed, a possibility that is mentioned by the N.E.L Device Team in their own report, should be investigated to see if it offers a cheaper solution.

3.1.4 H.R.S. Device

Concrete caissons (61% of the Total Cost)

The extremely high cost of constructing the massive caissons of the HRS device and the associated high cost of towing and placing into position (11.7% of the total cost) is a function of their physical size and the need to resist differential heads of water across the caisson walls of up to 12 metres. Further development of this device should aim at reducing the concrete volume to less than half of that indicated in the Reference Design with consequential savings in the cost of construction, steel components and installation costs.

Discussions should be held with the Device Team in the near future to agree the possible method by which this aim might be achieved.

3.2 General Conclusions Drawn from the Device Costings

The indication is that the preliminary cost of the Reference Designs varies from high to very high and the costs are roughly proportional to the size of the structure. Testing and design now need to go forward together to achieve more cost effective design. Reduction of the cost of the Civil Works is seen as the largest single priority.

TABLE 1

200 MW OUTPUT WAVE POWER DEVICES

SUMMARY OF CAPITAL COSTS

Description of Item	COST £M			
	S.E.A	WAVEPOWER	N.E.L	H.R.S
Construct concrete units and launch	(140 ducks) 154.1	(80 barges) 131.0	(28 units) 200.5	(40 units) 392.9
Structural steel components to units and seals	29.4	29.9	154.6	51.3
Mechanical components to power take-off	27.4	42.5	3.6	NIL
Hydraulic motors, turbines and electrical components to power take-off	27.1	32.8	50.4	82.8
Tow units to installation site, and moor or place	3.2	12.0	7.0	75.2
Anchors and Moorings	16.0	50.0	30.0	NIL
Power collection and transmission	41.8	46.8	36.3	40.1
Total capital cost	£ 299M	£ 345M	£ 482M	£642M
Capital cost/kw				
On the basis of 200 MW output	£1495	£1725	£2410	£3210
On the basis of 130 MW Mean Annual Output	£2300	£2654	£3708	£4938

TABLE 2

200 MW OUTPUT WAVE POWER DEVICES

SUMMARY OF CAPITAL COSTS AS A PERCENTAGE

Description of Item	Percentage of Total Cost			
	S.E.A	WAVEPOWER	N.E.L.	H.R.S
Construct concrete units and and launch	51.4	38.0	41.5	61.1
Structural steel components to units and seals	9.8	8.6	32.1	8.0
Mechanical components to power take-off	9.2	12.3	0.7	-
Hydraulic motors, turbine and electrical components to power take-off	9.1	9.5	10.5	12.9
Tow units to installation site and moor or place	1.1	3.5	1.5	11.7
Anchors and Moorings	5.4	14.5	6.2	-
Power collection & transmission	14.0	13.6	7.5	6.3
Total	100.0	100.0	100.0	100.0

APPENDIX A

PRICING OF CIVIL WORKS

A. CIVIL WORKS

1.0 Summary of Prices Received from Contractors and Interpretation of Approximate Cost Estimates

Three major contractors were asked to prepare approximate cost-estimates for the civil works for the two Devices originating from the following research organisations:-

i) Hydraulics Research Station (HRS)
ii) National Engineering Laboratories (NEL)

One contractor has priced the Device originating from Wavepower Ltd.

Comparisons have been made between the contractors' individual rates (Table 2) and for the overall costs for each Device (Table 2). From these figures, average and the lowest composite estimated costs have been tabulated.

In addition an estimate of cost of the civil works has been prepared for the Salter Duck using as a basis where practicable, the contractors' rates for the other Devices.

2.0 Selection of the Lowest Composite Prices

Significant differences in values have been estimated by the contractors for rates and prices of the operations associated with each Device. Using the values provided, one assumption could be that the lowest likely estimate in a future competitive situation would be simulated by taking a combination of the lowest estimated construction cost and the lowest float-out and place (or moor) cost. The evaluation of this lowest composite cost is given for each of the schemes in Tables 3, 4 and 5 respectively.

However, in order to take a more conservative interpretation of likely costs, an Arithmetic Average has been calculated. These are also tabulated in the above Tables. The average for the Wavepower Ltd. Device, has been calculated by reducing the only estimate for the Device by the percentage (approximately 25%) increase in this Contractor's estimate for the other two Devices over the average for those Devices.

3.0 Sources of Prices and Significance to Study

The sources of the prices are the three major contractors -

G. Wimpey & Co. Ltd.
Sir R. McAlpine & Sons Ltd.
ANDOC Ltd.

All three contractors have built and have access to dry docks suitable for the construction of oil-production platforms, together with a protected water mooring for the purpose of fitting out and second-stage construction.

Two of the contractors, G.Wimpey & Co.Ltd. and Sir R. McAlpine & Sons Ltd. have constructed oil-production platforms in these yards. McAlpine are, however, the only one of the three to have constructed a large concrete gravity structure in the U.K., since Andoc's experience in constructing a gravity platform was in their Dutch yard.

All contractors were requested to consider the specification and tolerances for the Device structures as being those generally applicable in the civil engineering industry, rather than those experienced by contractors when working on oil industry products.

In preparing their estimates, the contractors have made assumptions and exclusions, which they have submitted with their cost estimates and these are indicated in Tables 7/1, 7/2 and 7/3.

The rates and prices submitted by the Contractors have been examined for their adequacy on individual operational bases. It is felt that in general, the contractors have priced on a reasonable basis, although the rates used by Andoc are in some instances, distinctly low and are perhaps related to a particular cost-experience, bearing in mind their continental experience in this respect.

4.0 Pricing of the S.E.A. Device and Mooring Systems for Floating Devices

The S.E.A. Device has not been priced by the contractors. Where their rates used for other Devices apply they have been used, otherwise rates have been adjusted and applied by judgement. The method of construction indicated in the drawings of the Reference Design has been priced on the basis of a 12 month programme for the casting and assembly of 7 beak and spin units, but this aspect should be reviewed by contractors since the overall cost of civil works is sensitive to the time element.

The estimated cost of the mooring systems has been arrived at without benefit of contractors or in-house experience and have been based on very preliminary designs of possible mooring systems. Designs of mooring systems will have to be evaluated more closely before more meaningful costing can be carried out.

5.0 Pricing of the 400 MW Converter Station

This has been priced by applying selected contractors' rates to quantities obtained by examining the sketch-drawing prepared by the Consultants. It has been assumed that the structure will be piled and anchored and constructed in precast concrete with the helicopter platform in steel. It has further been assumed that the interior is divided into six rooms on two floors. The preliminary Bill of Quantities is given on Table 6.

6.0 Programme

All three contractors have prepared programmes for the HRS and NEL Devices for a 200 MW station, that is 40 and 28 units respectively, built over a period of 5 years. One contractor however, only indicated an overall construction time but which appears very similar to that given by the other contractors and for

comparison purposes is considered to be the same in detail. A comparison of programmes for an individual unit is given on Table 8. None of the three contractors currently have facilities capable of constructing all these units within the five year period and they have assumed either that other facilities would be made available or that further docks would be constructed. The current capacity of each facility based on their own programme is given in Table 9 together with proposals for augmenting those facilities. It will be noted that the construction period of each unit is shorter and the output greater (per unit area of dock) from the facility at Hunterston than for either of the other facilities. For the purpose of the 2nd stage construction - and storage if necessary - both Nigg and Ardyne have protected water available and probably capable of accommodating the entire construction scheme. Suitable mooring facilities are also available at Hunterston and the extension of the dock and providing a more suitable flooding system than presently exists, are practicable improvements, which could readily be provided.

The Wavepower Ltd. Device has only been considered by one contractor who has made the assumption that all the units would be constructed together in a facility purpose built for the units. It will be possible to construct these units on existing slipways and dry docks as well as in existing oil-rig construction yards and a variety of ad-hoc coastal situations. The construction cycle of one year would enable 5 units to be built at each base making a total of 16 bases being required to construct all 80 units.

It is understood that the S.E.A. Device units could be built and fabricated within a dry dock, but as no contractor has currently considered the scheme and the opportunity to examine various construction methods has not been possible, an assumption has been made of a combination of constructing individual parts of the unit by conventional precasting methods followed by assembly by post tensioning.

Consideration has been given to the possibility of constructing and placing sufficient Devices for the generation of 2000 MW of power over a period of ten years. To this end the total demand on the industry has been briefly considered. This information is given in Table 10.

On this basis, for the HRS and NEL schemes, it can be seen that further facilities similar to Nigg Bay will need to be constructed. The further needs of the Wave Power Devices and the S.E.A. Device are impossible to estimate without a thorough and lengthy study of existing facilities, but are thought likely to be less than those for the other two Devices.

7.0 Resources Required and Manpower Employed

For each of the major material resources, that is cement, steel and timber, the total quantities required have been estimated on a yearly basis for the 200 MW and the 2000 MW programmes, and for each Device. This is given in Table 11. In addition, consideration has been given to the number of men directly employed on the construction. Table 12 gives roughly the manpower required for each of the two programmes, 200 MW and 2000 MW on the basis of assuming that one third of the cost is attributable to Labour Costs, and that the average all-in labour rate is currently £2.5/h. These labour resources do not include for design, professional technical control and supervision or for the installation of mechanical and electrical equipment.

TABLE A.1

EVALUATION BY CONTRACTORS - CIVIL WORKS ONLY

		AS PRESENTED			TOTAL ADJUSTED TO INCLUDE ALL OPERATORS					
		CONTRACTOR			CONTRACTOR				LOWEST	
		1 £M	2 £M	3 £M	1 £M	2 £M	3 £M		COMPOSITE RATES £M	AVERAGE RATES £M
H.R.S. DEVICE	Hire of Dock	incl. (0.725)	1.186	0.771						
	Extra On-Cost	incl.	4.917	0.51						
	Construct	8.27	6.814	4.759	8.27	13.07	6.57		6.395	9.30
	Prepare, tow & place	1.48	1.982	4.005 excl. Shear Key. excl. 2nd stage tow	1.48*	1.831	3.701		1.48	2.34
	Total per unit	9.75	14.9	10.095	9.75	14.901	10.271		7.875	11.64
	Total for 40 No.	-	-	-	390.00	596.04	410.84		304.03	465.60
N.E.L.DEVICE	Hire of Dock	Incl	1.186	0.771						
	Extra On-Costs	Incl	4.480	0.51						
	Construct	12.08	9.081	8.475	12.08	16.21	9.76		10.10	12.68
	Prepare, tow & place	0.45	1.463	excl.	0.45	0.45ø	0.45ø		0.45ø	0.45ø
	Total per unit	12.53	16.21	9.756	12.53	16.66	10.21		10.55	13.13
	Total for 28 No.	-	-	-	350.84	466.48	285.88		295.5	367.64
W.P.L. DEVICE	Hire of Dock	-	incl	-	-	-	-		-	-
	Extra On-Costs	-	0.636	-	-	-	-		-	-
	Construct	-	1.494	-	-	2.13	-		1.513⊠	1.592
	Prepare, tow & place	-	-	-	-	0.150+	-		0.150+	0.150+
	Total per unit	-	2.13	-	-	2.28	-		1.663	1.742
	Total for 80 No.	-	-	-	-	182.40	-		133.044	139.38

* not known if includes seal and connect (assumed does)
ø not priced
⊠ Compared from average rates
\+ Assumed figure

TABLE A.2

COMPARISON OF RATES FROM CONTRACTORS' EVALUATIONS

		CONTRACTOR 1		CONTRACTOR 2		CONTRACTOR 3			
		BASIC £	FULL £	BASIC £	FULL £	BASIC £	FULL £	ARITHMETIC AVERAGE £	LOWEST RATE £
A Concrete	H.R.S	-	39/M^3	29.3/M^3	50.4	22.5	24.9	38.1	24.9
	N.E.L	-	39/M^3	29.5/M^3	44.1	23.5	26.0	36.4	26.0
	W.P.L	-	-	23.6/M^3	32.7	-	-	32.7	32.7
B Framework	H.R.S	-	17/M^2	19.3/M^2	33.2	14.0	15.5	21.9	15.5
	N.E.L	-	17/M^2	20.3/M^2	30.3	14.2 Av	15.82	21.0	15.82
	W.P.L	-	-	16.2/M^2	22.4	-	-	22.4	22.4
C Reinforce-	H.R.S	-	396/T	293/T	504	236	261	387	261
ment	N.E.L	-	396/T	300/T	448	236	261	368	261
	W.P.L	-	-	303/T	419	-	-	419	419
D Ballast	H.R.S	-	-	-	-	2.42	2.68	-	-
	N.E.L	-	-	5.53/M^3	8.23	-	-	8.23	8.23
	W.P.L	-	-	-	-	-	-		
E Rockfill	H.R.S	-	-	-	-	29.76	32.95	32.95	32.95
	N.E.L	-							
	W.P.L	-							
F Steelwork	N.E.L	-	1000/T	717/T Av.	1071/T	700/T Av.	775	948.7	775
G Prestressing	W.P.L	-	-	1392/T	1927/T	-	-	1927	1927
Other Items			£M		£M		£M	£M	£m
H Hire of Dock	H.R.S	-	0.725		1.186		0.77	0.894	0.725
& fit out	N.E.L		0.725		1.186		0.77	0.894	0.725
	W.P.L		N.P		0.067		N.P	0.067	0.067
J Tow Out	H.R.S.		inc.in L		0.261		0.500	0.381	0.261
	N.E.L				N.P		N.P	-	-
	W.P.L		N.P		0.062		N.P	0.062	0.062
K Ballasting	H.R.S		0.417		0.533		2.080	1.010	0.417
& 2nd stage	N.E.L		N.R		0.986		N.P	0.986	0.986
constr.	W.P.L		N.R		N.R		N.P		
L Place	H.R.S.		1.472		0.968		1.395	1.278	0.968
	N.E.L		0.444		N.P		N.P	0.444	0.444
	W.P.L		N.P		N.P		N.P	-	-
M Seal &	H.R.S.		INC.IN L		0.221		N.P	0.221	0.221
connect	N.E.L		N.R		N.P		N.P	-	-
	W.P.L		N.P		N.P		N.P	-	-

TABLE A.3.

H.R.S. DEVICE - LOWEST COMPOSITE PRICES FOR 200 MW

DESCRIPTION	QUANTITY	AVERAGE		LOWEST COMPOSITE	
		RATE	TOTAL £	RATE	TOTAL £
A Hire of Dry Dock & Fitting Out	Sum	984,000	984,000	725,000	725,000
B Concrete	54662 M^3	38.1	2,082,622	25.0	1,366,550
C Formwork	61015 M^2	21.9	1,336,229	15.5	945,733
D Reinforcement	10373 T	387	4,014,351	261	2,707,353
E Sundries	Sum	331,333	331,333	Nil	Nil
F Ballasting & 2nd Stage Construction	Sum	1,010,000	1,010,000	417,000	417,000
G Tow out	Sum	381,000	381,000	250,000	250,000
H Place	Sum	1,278,000	1,278,000	968,000	968,000
J Seal and Connect	Sum	221,000	221,000	221,000	221,000*
			£11.638,535m = £11.64m x 40 = £465.60 m		£7,600,636 x 40 No units = £304.03m

* Excluded from summary

TABLE A.4

N.E.L. DEVICE - LOWEST COMPOSITE PRICE FOR 200 MW

DESCRIPTION	QUANTITY	AVERAGE		LOWEST COMPOSITE	
		RATE	TOTAL £	RATE	TOTAL £
A Hire of Dock and fitting out	Sum		894,000	725,000	725,000
B Concrete	35,650 M^3	36.4	1,297,660	26.0	926,900
C Formwork	62,700 M^2	21.0	1,316,700	16.0	1,003,200
D Reinforcement	7,500 T	368	2,760,000	261	1,957,500
E Steelwork	5,821 T	948.7	5,522,383	775	4,511,275
F Ballasting & 2nd Stage Construction	Sum		493,000	986,000	986,000
G Tow out & place (S.B.M)	Sum		(444,000)	444,000	444,000 *
H Miscellaneous	Sum		405,000	Nil	-
		£13,132,743 = £13.13m x 28 No.= £367.64m Price used = £367.64 - £12.6 = £355.13M		£10,553,875 x 28 No. = £295.509m	

* Priced by Contractor 1 only, based on a Single Buoy Mooring and is not considered to be applicable.

TABLE A.5

WAVEPOWER LTD. DEVICE - LOWEST COMPOSITE PRICES FOR 200 MW

DESCRIPTION	QUANTITY	AVERAGE		LOWEST COMPOSITE	
		RATE	TOTAL £	RATE	TOTAL £
A Preparation and hire of facility	SUM	50,500	50,500	60,000	60,000
B Concrete	5900 M^3	24.7	147,730	25	147,500
C Shutters	23178 M^2	14.8	343,034	15.0	347,670
D Reinforcement	590 T	322	189,980	261	153,990
E Prestressing	385 T	1,482	570,570	1,927	741,895
F Sundries	Sum	200,000	200,000	Nil	Nil
G Tow out of facility	Sum	90,500	90,500	62,000	62,000
H Tow to site, moor and place	Sum	150,000	150,000	150,000 *	150,000 *
		£1,742,314 x 80 No = £139.38512m Price used = £139.38 - £12.0 + £3.6 = £130.98 m		£1,663,055 x 80 No = £133.044 m	

* Assumed figure not considered applicable.

TABLE A.6

ESTIMATED COST OF 400 MW CONVERTER STATION

(Civil Works Only)

DESCRIPTION	QUANTITY	UNIT	RATE £	£
Legs - 6 No. legs 3500T/leg. Use a cluster of 10 No. piles per leg. = 6 x 10 x 75 x 0.313 = 1408 tons.	1400	Tonnes	700	980,000
Bracing - say 1500 Tons	1500	Tonnes	1000	1,500,000
Anchors	6	No	25,000	150,000
Concrete	7066	M^3	40	282,640
Shutters	31947	M^2	20	638,940
Reinforcement	816	Tonnes	400	326,400
Helicopter platform - steel @ 30 x 30 = 900 M^2 @ £250/M^2				225,000
Sundries, furniture, fittings, extra on costs etc. (exclusive of mechanical & electrical plant) say				1,000,000
				£5,102,980 say £5.1m

EXCLUSIONS AND ASSUMPTIONS IN CONTRACTORS' EVALUATIONS

	H.R.S.
Contractor 1.	1) Based on constructing at Nigg Bay. 2) Overall time/unit = 9 units in 5 years. 3) Second stage ballasting in Cromarty Forth 4) A further two facilities would be required for 40 units in 5 year programme. 5) All at July 1977 cost 6) Design and supervision by others 7) No M & E works included
Contractor 2.	1) Dimensions and quantities all based on drawing supplied at meeting 6th July. 2) No prestressing 3) Float-out from construction basin can be achieved with 12 metre draught 4) Assumes use of existing facilities. 5) Design and Certification Fees excluded. 6) Current prices with no allowance for inflation 7) Installation of gate flaps, crane and complete mechanical and electrical plant at permanent position excluded. 8) Provision of cranes , etc. for installation of turbines, etc. in dock included. 9) Tow to Hebrides included. 10) A suitable system of ballasting and anchoring can be devices to enable accurate positioning of the units on the sea bed. 11) Weather window will allow 9 units to be placed in position each year. 12) Facilities are available. This estimate is based on the use of existing facilities available for use to construct oil production platforms. The Ardyne Point facility would be capable of producing 15 units in 5 years. Each dock would have 2 or 3 caissons constructed in it simultaneously with about a 14 month construction period from commencement to tow-out. Without accurate knowledge of the sea and sea bed conditions it is difficult to estimate the cost and time required for sinking these units onto the sea bed. Longitudinal dividing walls may be necessary along with a controlled immersion system, to enable differential ballasting of the units, and even with these, accurate placing of the units may be difficult in waves exceeding 2 metres. At the proposed water depth, waves of 8 metres or more will move rock used to level the sea bed, so quantities and programme time for placing the rock may be under-estimated.

Table 7/1 Contd...

Table 7/1 Contd..
Exclusions and Assumptions in Contractors' Evaluations

	H.R.S.
Contractor 3.	1. The sequence of events shown under the heading "Construction Notes" on the preliminary drawings has been used as a basic for the construction programme and form the method statement with the exception of the following points: a) Two caissons would be constructed at one time within the dry dock and not three as indicated on the drawing. b) The rock fill to be deposited at site would not be quarried within our activities but purchased as a part of a sub-contract for supply and installation at site. c) All marine operations at site would be serviced and controlled from an accommodation vessel and not from a land base. 2. Hydraulic key and infill excluded.

EXCLUSIONS AND ASSUMPTIONS IN CONTRACTORS' EVALUATIONS

	N.E.L.
Contractor 1.	1) Based on construction at Nigg Bay. 2) Overall time = 9 units in $4\frac{1}{2}$ years. 3) Based on mooring to a S.B.M. 4) A further 2 facilities required for 28 units in 5 year programme. 5) All at July 1977 cost. 6) Design and supervision by others. 7) No M & E works included. 8) Assume draught of unit O.K.
Contractor 2.	1) Dimensions and quantities based on drawing and bill supplied by Consultants. 2) No prestressing. 3) Design and Certificate Fees excluded. 4) Current prices with no allowance for inflation. 5) Supply and installation of generators excluded. 6) Supply and installation of ball valves excluded. 7) Estimate is ex-construction yard with no allowance for towing and permanent moorings. 8) A float-out draught of 12-13 metres can be achieved. 9) Temporary gates used to reduce draught at float-out and which can be re-used for subsequent float-outs. 10) Facilities are available. This estimate is based on the use of existing facilities available for use to construct oil production platforms. The Ardyne Point facility would be capable of producing 15 units in 5 years. This budget is based on constructing 2 or 3 caissons in each dock but the bulk of structural steelwork would be erected whilst the caisson was anchored at the temporary moorings at the facility. As no information is available on the behaviour of the units at sea or of the wave conditions at the permanent moorings, it is not possible to estimate the cost of mooring at the permanent position. The type and position of the moorings will affect the rocking motion and the amount of power generated.
Contractor 3.	There being no "Construction Notes" provided the following sequence of events has been used as a basis for submission: 1) Cast lower base slab in three sections to give repetitive use of formwork and thus create a 'ladder' effect for following activities. 2) Cast base rib walls in three sections etc. and including part of stern ribs. 3) Cast upper base slab in three sections, etc.

Table 7/2 Contd...

Table 7/2 Contd.
Exclusions and Assumptions in Contractors' Evaluations

	N.E.L.
Contractor 3. (Contd.)	4) Construct outer walls to caisson, complete stern ribs and fix steelwork. 5) Add temporary ballast and float out of dry dock and moor at deep dock. 6) Complete all caisson walls. 7) Cast roof of caisson. 8) Erect structural steel floor, downstand and superstructure. 9) Towing and mooring excluded.

TABLE 7/3

EXCLUSIONS AND ASSUMPTIONS IN CONTRACTORS' EVALUATIONS

	WAVEPOWER LTD.
Contractor 1.	Not priced
Contractor 2.	1) Quantities and dimensions as on Wavepower drawing No.2177.201 2) All mechanical content excluded. 3) Supply and installation of generators excluded. 4) Design and Certification Fees excluded. 5) Estimate is ex construction yard and excluded towing to and provision of ex permanent moorings. 6) 100 units constructed in a period of 5 years. 7) Current prices with no allowance for inflation. 8) Temporary moorings at construction yard, if tow to permanent moorings is delayed by weather window, are excluded. The shallow draught of these units would enable them to be constructed at a number of locations in the U.K. However, for this estimate it has been assumed that one new facility would be constructed to build all 100 units in 5 years. The Government or Planning Authorities may insist that a number of smaller facilities be built each capable of producing 20 to 30 units in 5 years. This would involve slight additional cost. As no information is available on the behaviour of the units at sea or of the wave conditions at the permanent moorings, it is not possible to estimate the cost of mooring at the permanent position.
Contractor 3.	Not priced.

TABLE A.8

COMPARISON OF PROGRAMMES

TIME FOR EACH UNIT

	Contractor 1	Contract 2	Contractor 3
H.R.S			
1. Prepare Dock		5 months	1 month
2. Construct in dock		14 months	7 months
3. 2nd stage construct	30 months	5 months	1 month
4. Place	(No detail		3 months
5. Cycle time/unit	available)	16 months	12 months
6. Dock reinstatement		2 months	3.5 months
N.E.L			
1. Prepare dock		5 months	1 month
2. Construct in dock		13 months	7 months
3. 2nd stage construct	24 months		3 months
4. Float out & place	(No detail	6 months	1 month
5. Cycle time/unit	available)	16 months	12 months
6. Dock reinstatement		2 months	3.5 months
WAVEPOWER LTD			
1. Prepare dock		7 months	
2. Construct	(not	8 months	(not
3. Tow out & place		1 month	
4. Cycle time/unit		10 months	
5. Dock reinstatement	considered)	1 month	considered)

TABLE A.9

CONSTRUCTION DOCKS REQUIRED FOR DEVICES FOR 200 MW STATION

ON 5 YEAR PROGRAMME

DOCK	PRODUCTION FROM EXISTING DOCK		PROPOSED EXTENSION	
	H.R.S	N.E.L	H.R.S.	N.E.L
Nigg Bay	9 No.	9 No.	Nigg enlarged to cater for 4 No. units at one time. A further 2 No. 4 unit docks built giving 36 No. units in 5 years. (40 No. required)	A further two docks built for 3 units giving 27 No. units in 5 years. (28 No. required)
Brent Dock (Ardyne Point)	9 No.	9 No.	A further 3 docks required one as Cormorant, two as Brent, giving 39 units in 5 years (40 No. required)	A further 2 docks required as existing docks.
Cormorant Dock	6 No.	6 No.		
Hunterston (Clyde)	10 No.	10 No.	Hunterston enlarged to take extra units making 15 No. One unit dock constructed to give 35 No. units in 5 years. (40 No. required)	Hunterston enlarged to take one extra unit. One 3 unit dock constructed to give 30 No. units in 5 years.

TABLE A.10

FACILITIES REQUIRED FOR 2000 MW STATION BUILT OVER 10 YEARS

DEVICE	UNITS REQUIRED	VARIOUS ESTIMATES OF FACILITIES REQUIRED			
		Contractor 1	Contractor 2	Contractor 3	Assumed
1. H.R.S.	400	21 No. yards as Nigg	14 No. yards as Ardyne Point	20 No. yards as Hunterston	-
2. N.E.L	280	16 No. yards as Nigg	10 No. yards as Ardyne Point	14 No. yards as Hunterston	-
3. WAVEPOWER LTD.	800	-	5 No. yards as facility described	-	Ad-hoc sites throughout U.K.
4. S.E.A	1400	-	-	-	Ad-hoc casting yards plus 20 No. large (250m x 30m) dry docks.

TABLE A.11

MATERIALS REQUIRED FOR 200 MW AND 2000 MW PROGRAMMES PER ANNUM

MATERIAL	200 MW				2000 MW			
	H.R.S	N.E.L	W.P.L	SEA	H.R.S	N.E.L	W.P.L	SEA
1. Cement	175000 T/A	80000 T/A	40000 T/A	30000 T/A	875000 T/A	400000 T/A	200000 T/A	150000 T/A
2. Aggregate/Ballast	800000 T/A	360000 T/A	170000 T/A	130000 T/A	400000 T/A	1800000 T/A	850000 T/A	650000 T/A
3. Reinforcement	83000 T/A	42000 T/A	9440 T/A + prestressing.	13000 T/A	415000 T/A	210000 T/A	47200 T/A	65000 T/A
4. Structural Steel	-	33000 T/A	-	-	-	165000 T/A	-	-
5. Timber - MC	1700 MC/A	1200 MC/A	1100 MC/A	1000 MC/A	8500 MC/A	6000 MC/A	5500 MC/A	5000 MC/A
6. Plywood - MS	80000 M^2/A	70000 M^2/A	75000 M^2/A	65000 M^2/A	400000 M^2/A	360000 M^2/A	375000 M^2/A	325000 M^2/A

TABLE A.12

LABOUR REQUIRED FOR CONSTRUCTION (CIVIL)

	200 MW OVER 5 YEARS				2000 MW OVER 10 YEARS			
	H.R.S.	N.E.L	W.P.L	SEA	H.R.S	N.E.L	W.P.L	SEA
	40 No.	28 No.	80 No.	140 No	400 No.	280 No.	800 No.	1400 No
Contractor 1	4,300	3,900	-	-	21,500	19,500	-	-
Contractor 2	6,500	5,200	2,400	-	32,500	26,000	12,000	-
Contractor 3	4,500	3,200	-	-	22,500	16,000	-	-
Average	5,100	4,100	1,800	2,000	25,500	20,500	9,000	10,000

The above is based on labour representing 0.33 of the total cost average over the period.

APPENDIX B

PRICING OF STRUCTURAL AND MECHANICAL COMPONENTS

PRICING OF STRUCTURAL AND MECHANICAL COMPONENTS (EXCLUDING MECHANICAL PLANT)

1. The pricing of the structural and mechanical components of the Devices has been carried out by the Consultants from their experience of the current prices and costs of the manufacturing of certain classes of fabricated steel components.

The following rates have been used for the various general categories described and cover for the material and workmanship content plus a paint protection system and final installation costs. Of necessity, these categories are broad in concept and in determining the price to be used for a particular component, the Consultants have used their judgement as to which price category the component belongs.

(a)	Fabricated steel components where workmanship content relatively low. (i.e. simple welded structures).	-	£750 per tonne
(b)	Fabricated steel components where workmanship content relatively high (i.e. components which require some machinery).	-	£900/£1,000 per tonne
(c)	General steel castings (where some machinery is required).	-	£1,000 per tonne

2. For certain components of some of the Devices, which lay outside the Consultants up-to-date pricing knowledge, advice was sought from a number of manufacturers who were provided with a simple sketch of the component and were asked to determine a price on the basis of the largest number-off required.

The manufacturers who were contacted in this way, were the following:-

(a)	Davy-Loewy, Sheffield Approx. price for machine cast racks	-	£1,200 per tonne
(b)	Andre Rubber Co. Approx. price for the cylindrical and circular laminated rubber bearings for the SEA Device.	-	£2,000 each
(c)	British Steel Corporation 40 mm dia. prestressing bars (supply only)	-	£2.75/metre
	40 mm dia. nuts	-	£1.35 each
	40 mm dia. washers	-	£0.18 each

APPENDIX C

PRICING OF MECHANICAL AND ELECTRICAL PLANT AND POWER TRANSMISSION

PRICING OF MECHANICAL AND ELECTRICAL PLANT AND POWER TRANSMISSION

1. Basis of Budgetary Estimates

The estimates required in the tabular summaries for the Power Collection and Transmission costs for each Device all relate to a nominal 200 MW installation. Transmission design is based on 400 MW and 2,000 MW systems and the 200 MW costs quoted are therefore an appropriate proportion of the actual installation cost.

The estimates cover all mechanical and electrical plant and some associated civil costs and include bulk power transmission through the Highlands to an AC power delivery point, which might be in the Perth area, so as to feed directly into the Scottish high voltage network.

The costs represent current 1977 prices without future escalation and have been based, where possible, on estimates from manufacturers, but are otherwise built up from relevant cost data available in the Consultants current records.

It should be stressed that the estimates are of current contract prices only including supply, delivery and installation. They do not include any provision for the following:-

(a) Contingencies arising during design and construction.

(b) Engineering, design and the supervision of manufacture, construction and setting to work.

(c) Project management including financing and legal charges.

(d) The purchase of land and property and payments for wayleaves, compensation and Admiralty charges.

(e) Interest charges on annual capital investments.

TABLE C.1 PLANT AND TRANSMISSION COSTS

200 MW S.E.A. INSTALLATION

Item No.	Description	Section Cost £M	Group Cost £M
1	Hydraulic pumps, couplings; by-pass and control valves; micron filters; fixings.	6.220	
2	Pressure oil pipework; supports, expansion and flexible joints, valves.	5.000	
3	Flow regulation pressure vessels including gas cushion equipment.	0.300	
4	Oil hydraulic turbines 19,300 h.p. gauge panels, governors and controls.	8.400	
5	Auxiliary plant in power module. Crane etc.	0.400	
6	Hydraulic fluid.	2.000	
7	Generators 14 MW with control and protection.	3.200	
8	Transformers, switchgear and cabling in module.	1.540	
	Sub-total - Power Plant		27.060
9	22 kV submarine cables to platform. Switchgear and control equipment.	7.150	
10	Platform mounted 400 MW converter station complete. Excluding platform structure.	7.500	
11	Main ± 250 kV DC cables: submarine and land installations.	10.418	
12	Terminal DC substations - including buildings excluding quay facilities.	1.637	
13	Double circuit overhead line ± 250 kV DC with spare midpoint circuit, also high crossing at Kyle Rhea.	4.120	
14	Main inverter substation in central Scotland.	7.500	
15	Communications systems.	0.500	
	Sub-total - Power Collection and Transmission		38.825

TABLE C.2 PLANT AND TRANSMISSION COSTS

200 MW OUTPUT WAVEPOWER RAFT INSTALLATION

Item No.	Description	Section Cost £M	Group Cost £M
1	Hydraulic pumps, couplings; by-pass and control valves; micron filters; fixings.	4.91	
2	Pressure oil pipework; flow, return and drain. Special swivel joints. Valves and supports.	2.48	
3	Flow regulation pressure vessels including gas cushion equipment.	0.56	
4	Oil hydraulic turbines. 4750 h.p. including inlet control valve, governor and gauge panels.	12.40	
5	Auxiliary plant in rafts.	2.80	
6	Hydraulic fluid	0.48	
7	Generators. 3.5MW	6.40	
8	Electrical equipment including transformers, switchgear and cabling in rafts.	2.80	
	Sub-total - Power Plant		32.83
9	22 kV flexible submarine cables between rafts and to platform. Switchgear and control equipment.	12.05	
10	Platform mounted 400 MW convertor station complete. Excluding platform structure.	7.50	
11	Main ± 250 kV DC cables; submarine and land installations.	10.42	
12	Terminal DC substations - including buildings, excluding quay facilities.	1.64	
13	Double circuit overhead line ± 250 kV DC with spare midpoint circuit, also high crossing at Kyle Rhea.	4.12	
14	Main inverter substation in central Scotland.	7.50	
15	Communications systems.	0.50	
	Sub-total - Power Collection and Transmission		43.73

TABLE C.3 PLANT AND TRANSMISSION COSTS

200 MW OUTPUT N.E.L. INSTALLATION

Item No.	Description	Section Cost £M	Group Cost £M
1	Air pressure turbines 5000 h.p. 3 No. per 140 m unit	29.4	
2	Generators 3.5 MW 3 No. per unit	16.8	
3	3.3 kV switchgear. Control, protection, busbars and cabling	2.8	
4	Generator transformers 12 MVA 3.3/22 kV on type	1.4	
	Sub-total - Power Plant		50.4
5	22 kV flexible submarine cables between OWC Devices and convertor platform. 22 kV switch-gear; control and protection equipment, auxiliary plant.	4.6	
6	Platform mounted 400 MW convertor station complete. Excluding platform structure.	7.5	
7	Main ± 250 kV DC cables: Submarine and land installations.	10.4	
8	Terminal DC substations - including buildings, excluding quay facilities	1.7	
9	Double circuit overhead line ± 250 kC DC with spare midpoint circuit, also high crossing at Kyle Rhea	4.1	
10	Main inverter substation in central Scotland.	7.5	
11	Communications systems	0.5	
	Sub-total - Power Collection and Transmission		36.3

TABLE C.4 PLANT AND TRANSMISSION COSTS

200 MW OUTPUT H.R.S. INSTALLATION

Item No.	Description	Section Cost £M	Group Cost £M
1	Kaplan turbines: 8000 hp 60 r/m complete with governor and control equipment; auxiliaries; (turbine design for sea water application) 40 No. sets	54.00	
2	Alternators: 6.7 MVA complete with control and protection. 40 No. sets	24.00	
3	Auxiliary plant in caissons (allowance for)	2.00	
4	11 kV Busbars; switches; control and protection.	1.70	
5	Transformers: 27 MVA 11/33 kV; off-load T/C and ON coolers.	1.10	
	Sub-total - Power Plant		82.80
6	33 kV Cables 3 core 27 MVA total length 33.5 kilometres	5.00	
7	33 kV Switchgear in 400 MW converter station (50% cost).	0.40	
8	Platform mounted 400 MW converter station complete. Excluding platform structure.	7.50	
9	Main ± 250 kV DC cables; submarine and land installations (share of cost).	10.42	
10	Terminal DC substations - including buildings, excluding quay facilities.	1.64	
11	Double circuit overhead line to Perth including high crossing of Kyle Rhea (10% of cost)	4.12	
12	Main inverter substation in central Scotland (10% of cost).	7.50	
13	Communications systems.	0.50	
	Sub-total - Power Collection and Transmission		37.08

TABLE C.5 COMPARATIVE TABLE OF ESTIMATED COSTS OF PLANT AND TRANSMISSION (ALL BASED ON 200 MW)

		S.E.A.	WAVEPOWER Ltd.	N.E.L.	H.R.S.
Power Plant	£M	27.1	32.8	50.4	82.8
Power Collection and Transmission	£M	38.8	43.7	36.3	37.1
Total M & E Cost	£M	65.9	76.5	86.7	119.9

APPENDIX D

SUMMARY OF DEVICE COSTS

SUMMARY OF DEVICE COSTS
(ALL FOR 200 MW STATIONS)

DEVICE	ITEM DESCRIPTION	ESTIMATED COST £M
S.E.A. (140 Beaks)	1. Construct prestressed spines and beaks.	141.76
	2. Construct spine access sections (20 No.) and Power House sections (10 No.)	9.50
	3. Construct Universal Joint complete (15 No.)	5.71
	4. Fabricate and instal rack and pinion assembly.	27.40
	5. Fabricate and instal beak/spine roller system.	8.29
	6. Manufacture and instal rubber seals.	17.08
	7. Supply and instal servicing platforms (including support beams and track).	1.00
	8. Supply and instal hydraulic pumps, motors, generators and all auxiliary equipment.	27.06
	9. Tow units to installation site.	3.24
	10. Supply and instal anchors and moorings.	16.00
	11. Power Collection and Transmission	41.82
	Total for S.E.A. Device	£298.87M
WAVEPOWER LTD. (80 Barges)	1. Construct prestressed concrete rafts.	130.98
	2. Fabricate and instal hinges to rafts.	13.92
	3. Fabricate and instal rack and pinion assembly.	16.15
	4. Fabricate and instal pinnion carriage, guide wheels and guide track.	24.27
	5. Fabricate and instal link arms and machinery covers.	18.08
	6. Supply and instal hydraulic pumps, motors, generators and all auxiliary equipment.	32.83
	7. Tow units to installation site.	12.00
	8. Supply and instal anchors and moorings	50.00
	9. Power Collection and Transmission	46.78
	Total for WAVEPOWER Device	£344.90M
N.E.L. (28 Units)	1. Construct concrete caisson units, ballast and launch.	200.5
	2. Fabricate and instal steel sections.	154.6
	3. Manufacture and instal air inlet and outlet valve.	3.6
	4. Supply and instal air turbines, generators and auxiliary plant.	50.4
	5. Tow units to installation site.	7.0
	6. Supply and instal anchors and moorings	30.0
	7. Power Collection and Transmission	36.3
	Total for N.E.L. Device	£482.4M

/Contd.

SUMMARY OF DEVICE COSTS (Contd.)

DEVICE	ITEM DESCRIPTION	ESTIMATED COST £M
H. R.S (40 Units)	1. Construct concrete caisson units complete with temporary stop logs and launch.	390.4
	2. Construct concrete storage area caisson complete with telescopic crane.	2.5
	3. Fabricate and instal gate panels complete with flap gates.	49.3
	4. Supply and instal travelling gantry crane complete with track.	2.0
	5. Supply and instal Kaplan turbines, alternaters and auxiliary plant.	82.8
	6. Tow out caissons, prepare sea bed, place units and seal and connect.	75.2
	7. Power Collection and Transmission.	40.1
	Total for H.R.S. Device	£642.3M